APPENDIX 1

TERMINOLOGY IN FAULT DETECTION AND DIAGNOSIS

A1.1 STATES AND SIGNALS

- **Fault**: Unpermitted deviation of at least one characteristic property of the system
- **Failure**: Permanent interruption of a system’s ability to perform a required function under specified operating conditions
- **Malfunction**: Intermittent irregularity in fulfillment of a systems desired function
- **Error**: Deviation between a computed value (of an output variable) and a true, specified or theoretically correct value
- **Disturbances**: An unknown (and uncontrolled) input acting on a system
- **Perturbation**: An input acting on a system which results in a temporary departure from steady state
- **Residual**: Fault indicator, based on deviations between measurements and model equation based calculations
- **Symptoms**: Change of an observable quantity from normal behaviour.
A1.2 FUNCTIONS

- **Fault detection:** Determination of faults present in a system and time of determination

- **Fault isolation:** Determination of kind, location and time of detection of a fault by evaluating symptoms which follows fault detection

- **Fault identification:** Determination of the size and time-variant behaviour of a fault which follows fault isolation

- **Fault diagnosis:** Determination of kind, size, location and time of detection of a fault by evaluating symptoms. Followed by fault detection, including fault detection, isolation and identification

- **Monitoring:** A continuous real-time task of determining the possible conditions of a physical system, recognizing and indicating anomalies of the behaviour

- **Supervision:** Monitoring a physical system and taking appropriate actions to maintain the operation in the case of faults

- **Protection:** Means by which a potentially dangerous behaviour of the system is suppressed if possible or means by which the consequence of a dangerous behaviour are avoided
A1.3 MODELS

- **Quantitative model**: Use of static and dynamic relations among system variables and parameters in order to describe systems behaviour in quantitative mathematical terms.

- **Qualitative model**: Use of static and dynamic relations among system variables and parameters in order to describe systems behaviour in qualitative terms such as causalities or if-then rules.

- **Diagnostic model**: A set of static or dynamic relations which links specific input variables – the symptoms – to specific output variables – the faults.

- **Analytical redundancy**: use of two, but not necessarily identical ways to determine a quantity where one way uses a mathematical process models in analytical form.
APPENDIX 2

CONTROLLER DESIGN BY DAVISON’S METHOD

The $K_c$ and $K_I$ for the multivariable PI controller by Davison’s method are given by

$$K_c = \delta [G(s = 0)]^{-1} \quad (A2.1)$$

$$K_I = \varepsilon [G(s = 0)]^{-1} \quad (A2.2)$$

Here, $[G(s = 0)]^{-1}$ is called the rough tuning matrix and $\delta$ and $\varepsilon$ are the fine tuning parameters. The fine tuning parameters range is from 0 to 1 (the recommended values are $\delta = 0.1$ and $\varepsilon = 0.3$). If the system is not much interactive, the proportional gain can be permitted as large value. For the three-tank system, the system is made less interactive by choosing the operating point as $h_1 > h_2 > h_3$. Thus the tuning parameter can be varied greater than 1.

The obtained transfer function matrix is

$$\begin{bmatrix}
58.48S^2 + 2.382S + 0.0173727 & 0.006616 \\
S^3 + 0.05S^2 + 0.0006138S + 9.781 \times 10^{-7} & S^3 + 0.05S^2 + 0.0006138S + 9.781 \times 10^{-7} \\
0.006616 & 58.48S^2 + 1.8561S + 0.006616 \\
S^3 + 0.05S^2 + 0.0006138S + 9.781 \times 10^{-7} & S^3 + 0.05S^2 + 0.0006138S + 9.781 \times 10^{-7}
\end{bmatrix} \quad (A2.3)$$
From the transfer function matrix the gain matrix is calculated by substituting the term $S = 0$

$$G(s=0) = \begin{bmatrix} 17761 & 6763 \\ 6763 & 6763 \end{bmatrix}$$  \hspace{1cm} \text{(A2.4)}$$

For $\delta=10$ and $\varepsilon=0.1$ (which gave the better performance), the centralised PI controller values are $K_C$ and $K_I$

$$K_C = \begin{bmatrix} 0.090926 & -0.090926 \\ -0.090926 & 0.23877 \end{bmatrix} \times 10^{-2}$$ \hspace{1cm} \text{(A2.5)}

$$K_I = \begin{bmatrix} 0.090926 & -0.090926 \\ -0.090926 & 0.23877 \end{bmatrix} \times 10^{-4}$$ \hspace{1cm} \text{(A2.6)}

The Relative Gain Matrix (RGM) which relates the amount of interaction between the inputs and outputs is $\begin{bmatrix} 1.615 & -0.615 \\ -0.615 & 1.615 \end{bmatrix}$. From the RGM it can be inferred that the interaction between $Q_1$ and $h_1$ and $Q_2$ and $h_3$ are more compared to $Q_1$ and $h_3$ and $Q_2$ and $h_1$ since it is represented by the negative sign. Therefore the controller is designed by paring between $Q_1$ and $h_1$ and $Q_2$ and $h_3$. 

APPENDIX 3

SPECIFICATIONS OF DATA ACQUISITION CARD

**PCI-9112**

**Features**
- 32-bit PCI Bus with Bus-mastering DMA
- 12-bit analog input resolution
- 16 single-ended or 8 differential analog input
- On-board A/D FIFO memory
- Auto-scanning channel selection
- Up to 110 KHz A/D sampling rates
- Programmable gain of x0.5, x1, x2, x4, x8
- Bipolar or unipolar input signals
- Three A/D trigger modes: software trigger, programmable pace trigger, and external pulse trigger
- 16-bit digital input and 16-bit digital output
- Two 12-bit monolithic multiplying analog output channels
- 3 independent programmable 16-bit down counters
- Compact, half-size PCB
- 37-pin D-type connector

**Specifications**

**Analog Input (A10)**
- Converter: B.B. AD8774 or equivalent successive approximation type
- Resolution: 12-bit
- Input channels: 16 SE or 8 DI
- Input range: (programmable)
  - Bipolar: ±10V, ±8V, ±5V, ±2.5V, ±5V, ±10V
  - Unipolar: 0-10V, 0-5V, 0-2.5V, 0-1.25V
- Conversion time: 6μsec
- Sample Rate: 100K samples/sec maximum
- Overvoltage Protection Continuous ±10V maximum
- Accuracy:
  - Gain = 0.5, 1: 0.01% of FSR ±1 LSB
  - Gain = 2.4: 0.02% of FSR ±1 LSB
  - Gain = 8: 0.04% of FSR ±1 LSB

- Input Impedance: 10 MΩ
- Trigger mode: Software, pace, and external trigger
- Data transfer: Polling, Interrupt, Bus mastering DMA

**Analog Output (A10)**
- Number of channels: 2
- Resolution: 12-bit
- Output range:
  - Internal reference: unipolar 0-5V or 0-10V
  - External reference: ±10V or ±19V

**Programmable Counter**
- Device: 5254
- A/D pace: 32-bit timer (two 16-bit counters cascaded together) with a 2 MHz time base
- Counter: One 16-bit counter

**General Specifications**
- Connector: 37-pin D-type connector
- Operating temperature: 0ºC - 80ºC
- Storage temperature: -20ºC - 80ºC
- Humidity: 5-95% non-condensing
- Power requirement:
  - +5V @ 400mA typical
  - +12V @ 110mA typical
- Dimension: 173mm x 102mm

**Termination Boards**
- ACLK-9137
- ACLK-8125
- ACLK-9136
- DNL-STD

**Ordering Information**

PCI-9112
Advanced PCI Bus-mastering DAS Card

Note: The above products are shipped with software development kit for
DOS/WINDOWS/UNIX, PCI-DX/86 and PCI-VX/40.

**Pin Assignments for the 50-107 Connector of PCI-9112**

- (1) A0
- (2) A1
- (3) A2
- (4) A3
- (5) A4
- (6) A5
- (7) A6
- (8) A7
- (9) A.GND
- (10) A.GND
- (11) GND
- (12) ExRst (12)
- (13) ExRst (12)
- (14) A.GND
- (15) D.GND
- (16) A.GND
- (17) A.GND
- (18) N.C.
- (19) N.C.
- (20) +12V
- (21) +5V